

ISOTOPIC COMPOSITION OF THE ANOMALOUS LOW ENERGY COSMIC RAY NITROGEN AND OXYGEN

R. A. Mewaldt, E. C. Stone, S. B. Vidor and R. E. Vogt

California Institute of Technology
Pasadena, California 91125

The isotopic composition of the enhanced fluxes of cosmic ray nitrogen and oxygen observed below ~ 30 MeV/nuc is of interest, whether the nuclei are a sample from some nearby galactic source region which is underabundant in carbon, or a sample of the neutral interstellar medium. We have measured the enhanced fluxes in the 6 to 12 MeV/nuc energy interval over a two year period with the Caltech Electron/Isotope Spectrometer on IMP-7. The observed low energy nitrogen and oxygen nuclei are predominantly ^{14}N and ^{16}O , with upper limits (84% confidence level) of $^{15}\text{N}/\text{N} \leq 0.26$, $^{17}\text{O}/\text{O} \leq 0.13$, and $^{18}\text{O}/\text{O} \leq 0.12$ for other isotopes in the 6-12 MeV/nuc energy interval. The implications of these results for the origin of the enhanced nitrogen and oxygen fluxes are discussed.

1. Introduction. The elemental composition of the 3 to 30 MeV/nuc cosmic rays is anomalous in that the N and O fluxes are significantly enhanced relative to C (Hovestadt et al., 1973; McDonald et al., 1974). This anomalous composition suggests that the origin and possibly the isotopic composition of these enhanced fluxes is different from that of higher energy cosmic rays. Using the Caltech Electron/Isotope Spectrometer aboard the IMP-7 satellite, we have investigated the isotopic composition of 6-12 MeV/nuc nitrogen and oxygen nuclei.
2. Instrument. A schematic illustration of the IMP-7 EIS telescope is shown in *Figure 1*. For isotope analysis a ΔE vs. E technique was used. Particles are required to trigger the 50 μ thick detector D2 and the 1 mm thick detector D5, with all other detectors in anticoincidence. In this analysis mode the annular detectors D0, D1, D3, and D4 are active collimators and provide a clean, low background geometry. As a result of the collimation, the geometrical factor for D25 events is 0.07 cm^2sr . A more detailed discussion of the instrument can be found in the report by Hurford et al. (1974).
3. Observations. A plot of ΔE vs. residual energy for all our D25 data with $Z > 2$ is shown in *Figure 2* for the time period October 1972 - October 1974. For clarity, events that saturate the analog to digital converter of either D2 or D5 are not shown. However, no background has been subtracted from the plot. We have defined solar quiet periods as those days on which the average 4.3-12.6 MeV proton flux is $\leq 0.014 (\text{cm}^2\text{sr sec})^{-1}$. Days on which this proton flux is exceeded are referred to as solar active periods. This criterion is a useful one since the combined flux of low energy nitrogen and oxygen is essentially independent of the 4.3-12.6 MeV proton flux during the solar quiet

CALTECH ELECTRON/ISOTOPE SPECTROMETER

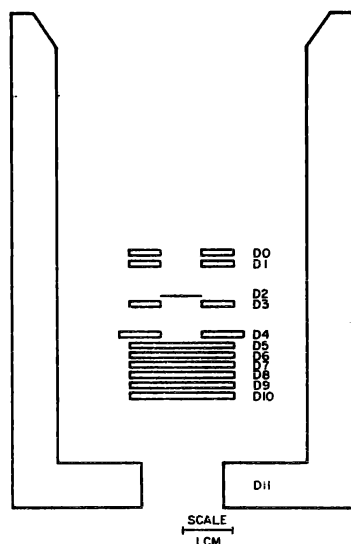


Fig. 1. Schematic illustration of the IMP-7 EIS Telescope. D0 through D10 are fully-depleted silicon surface barrier detectors, and D11 is a plastic scintillator.

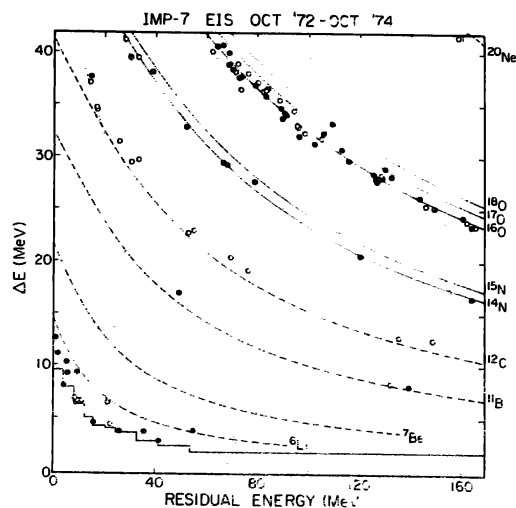


Fig. 2. Plot of ΔE vs. residual energy for D25 events with $Z > 2$. ● Solar quiet data. ○ Solar active data. Solid curves are predicted isotope tracks based on accelerator calibrations. Dashed curves are calculated using standard range-energy tables. Dotted lines bracket ~ 5-12.5 MeV/nuc. No data are shown below the broken line.

periods and is not sensitive to the exact value of the limit placed on the proton flux.

The solid curves in Figure 2 indicate the predicted tracks for the stable isotopes of nitrogen and oxygen based on an accelerator calibration of a spare telescope with nitrogen and oxygen beams. As a result of the calibration, these tracks are known to within ~ 0.05 amu (Vidor, 1975). The dashed curves indicate the predicted tracks for the elements lithium, beryllium, boron, carbon, and neon and were calculated using standard range - energy tables. From the accelerator calibration it was determined that the nitrogen and oxygen instrument response calculated from the standard range - energy tables alone was not accurate enough for isotope identification (Vidor, 1975). Therefore, the dashed lines should be used for element identification only.

By properly interpolating between the integral mass tracks, a non-integral effective mass can be assigned to each data point in Figure 2. The resulting mass histograms of the solar quiet time nitrogen and oxygen data are shown in Figure 3 and Figure 4. The Gaussian curves superimposed on the histograms indicate the expected response to a pure ^{14}N and ^{16}O composition. The widths of the curves represent the predicted mass resolution and are calculated from the physical parameters of the detector system.

Excluding the oxygen event near mass 18, the observed mean mass and the rms mass resolution are compared in Table 1 with the values expected for a pure ^{14}N and ^{16}O composition. The mean mass and the mass resolution of the solar quiet time nitrogen and oxygen data are consistent with the values expected from a pure ^{14}N and ^{16}O composition and are inconsistent with a large fraction of either ^{15}N or of ^{17}O or ^{18}O , which are the other stable isotopes of nitrogen and oxygen. As a consistency check on our knowledge of the mass response to nitrogen and oxygen, we have calculated the observed mean mass and rms mass resolution of the nitrogen and oxygen events obtained during solar active periods. The observed dominance of ^{14}N and ^{16}O during solar active periods is expected if the solar system abundances of Cameron (1973) are representative of solar cosmic rays. It should be noted that the expected mass resolution listed in Table 1 for the solar quiet nitrogen differs from the mass resolution expected for the solar active nitrogen because the average energies of the two sets of data differ and because the mass resolution of the instrument is somewhat energy dependent.

4. Results. Using the maximum likelihood technique, upper limits to the abundance of ^{15}N , ^{17}O , and ^{18}O in the low energy solar quiet time nitrogen and oxygen cosmic rays were obtained. The results are given in Table 2.

5. Discussion. The present measurement, which indicates that ^{14}N is the dominant nitrogen isotope in the low energy cosmic rays, contrasts with results in the energy range of ~ 50 -250 MeV/nuc, which indicate that ^{15}N comprises more than 50% of the nitrogen in these higher energy cosmic rays (Webber et al., 1973; Garcia-Munoz et al., 1974). The ^{15}N in the higher energy galactic cosmic rays is believed to result primarily from the fragmentation of oxygen cosmic ray nuclei which have passed through approximately 6 g/cm² of interstellar material (Shapiro et al., 1973). The lack of ^{15}N in the low energy cosmic rays is consistent with the lack of lithium, beryllium, boron, and

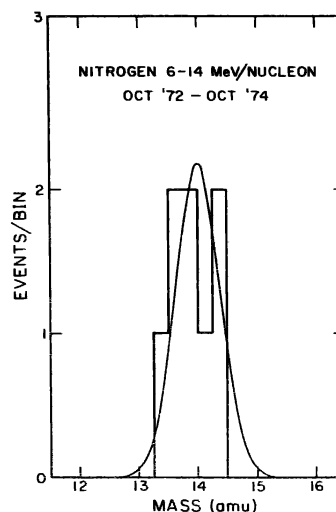


Fig. 3. Mass histogram of quiet time nitrogen data. The Gaussian curve shows the predicted instrument response to ^{14}N cosmic rays.

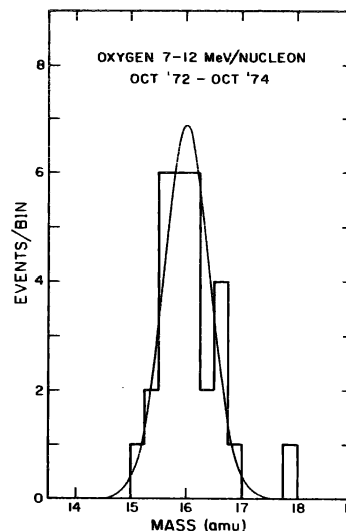


Fig. 4. Mass histogram of quiet time oxygen data. The Gaussian curve shows the predicted instrument response to ^{16}O cosmic rays.

TABLE 1

Mass Distributions of Low Energy Nitrogen and Oxygen Cosmic Rays

		SOLAR QUIET PERIODS		SOLAR ACTIVE PERIODS	
		<u>Observed</u>	<u>Expected*</u>	<u>Observed</u>	<u>Expected*</u>
Nitrogen	\bar{M} (amu)	13.94 \pm .13	14.00	13.94 \pm .08	14.00
	σ_M (amu)	0.38 \pm .10	0.37	0.12 $^{+.25}_{-.06}$	0.41
Oxygen	\bar{M} (amu)	15.98 \pm .08	15.99	15.92 \pm .10	15.99
	σ_M (amu)	0.43 \pm .06	0.42	0.46 \pm .07	0.42

* Calculated for pure ^{14}N and ^{16}O composition

TABLE 2

Isotopic Composition of the Low Energy Nitrogen and Oxygen Cosmic Rays

<u>Isotope Fraction</u>	<u>Energy (MeV/nucleon)</u>	<u>84% Confidence Interval</u>
$^{15}\text{N}/\text{N}$	5.6 - 12.7	≤ 0.26
$^{17}\text{O}/\text{O}$	7.0 - 11.8	≤ 0.13
$^{18}\text{O}/\text{O}$	7.0 - 11.2	≤ 0.12

carbon (Mewaldt et al., 1975). Thus, the quiet time cosmic rays observed at ~ 10 MeV/nuc differ in both elemental and isotopic composition from the galactic cosmic ray component observed at higher energies, providing strong evidence that the low energy nitrogen and oxygen fluxes are not simply a sample of the higher energy component that has been decelerated in the heliosphere.

We now consider the implications of the isotope measurements in relation to the possible origins of the anomalous low energy nitrogen and oxygen cosmic ray component. Fisk et al. (1974) proposed that these low energy cosmic rays originate from neutral interstellar particles which penetrate the solar cavity, are singly ionized, and are accelerated to several MeV/nuc. If there is no preferential acceleration of one isotope relative to another, then this local origin theory predicts that the isotopic composition of the low energy cosmic

rays should reflect the isotopic composition of the neutral interstellar gas. Making the reasonable assumption that the solar system abundances (Cameron, 1973) apply to the interstellar gas, the low energy nitrogen and oxygen cosmic rays are expected to be respectively 99.6% ^{14}N and 99.8% ^{16}O . The local acceleration theory is therefore consistent with our observations that ^{14}N and ^{16}O are the dominant isotopes of the low energy nitrogen and oxygen cosmic rays.

If, on the other hand, the low energy nitrogen and oxygen cosmic rays originate from a nearby galactic source, then any proposed nucleosynthesis process which is designed to produce enhancements of nitrogen and oxygen and depletion of carbon must simultaneously produce isotopic abundances consistent with our observations. The hot CNO cycle (Audouze *et al.*, 1973) or nova outbursts in white dwarfs (Starrfield *et al.*, 1972; Hoyle and Clayton, 1974) can produce an overabundance of nitrogen and oxygen relative to carbon. In particular, Hoyle and Clayton (1974) proposed that white dwarf novae could be the source of the low energy nitrogen and oxygen cosmic rays. They suggested that the ^{15}N and ^{17}O should be overabundant and, depending on initial conditions, perhaps even the dominant nitrogen and oxygen isotopes. The present measurements rule out any astrophysical source of these particles in which ^{15}N and ^{17}O are more abundant than ^{14}N and ^{16}O .

6. Acknowledgements. This work was supported in part by the National Aeronautics and Space Administration under Contract NAS5-11066 and Grant NGR 05-002-160.

7. References.

- Audouze, J., J. W. Truran, B. A. Zimmerman, "Hot CNO-Ne Cycle Hydrogen Burning I. Thermonuclear Evolution at Constant Temperature and Density", Astrophys. J., **184**, 493, 1973.
- Cameron, A. G. W., "A Critical Discussion of the Abundances of Nuclei", Explosive Nucleosynthesis, edited by D. N. Schramm and W. D. Arnett, University of Texas Press, Austin, 1973.
- Fisk, L., B. Kozlovsky, R. Ramaty, "An Interpretation of the Observed Oxygen and Nitrogen Enhancements in Low Energy Cosmic Rays", Astrophys. J., **190**, L351, 1974.
- Garcia-Munoz, M., G. M. Mason, J. A. Simpson, "The Isotopic Composition of Low Energy Nitrogen Galactic Cosmic Rays", Talk presented at the Symposium on Measurements and Interpretation of the Isotopic Composition of Solar and Galactic Cosmic Rays, Durham, New Hampshire, 1974.
- Hovestadt, D., O. Vollmer, G. Gloeckler, C. Y. Fan, "Differential Energy Spectra of Low Energy (< 8.5 MeV per Nucleon) Heavy Cosmic Rays during Solar Quiet Times", Phys. Rev. Lett., **31**, 650, 1973.
- Hoyle, F. and D. D. Clayton, "Nucleosynthesis in White Dwarf Atmospheres", Astrophys. J., **191**, 705, 1974.

- Hurford, G. J., R. A. Mewaldt, E. C. Stone, R. E. Vogt, "The Energy Spectrum of 0.16 to 2 MeV Electrons during Solar Quiet Times", Astrophys. J., 192, 541, 1974.
- McDonald, F. B., B. J. Teegarden, J. H. Trainor, W. R. Webber, "The Anomalous Abundance of Cosmic Ray Nitrogen and Oxygen Nuclei at Low Energies", Astrophys. J., 187, L105, 1974.
- Mewaldt, R. A., E. C. Stone, S. B. Vidor, R. E. Vogt, "The Elemental Composition of 4-30 MeV/nuc Cosmic Ray Nuclei with $1 \leq Z \leq 8$ ", Proceedings of the 14th Int. Cosmic Ray Conf., Munich, 1975.
- Shapiro, M. M., R. Silberberg, C. H. Tsao, "Relative Abundances of Cosmic Ray Nuclei at the Sources", 13th International Cosmic Ray Conference, Conf. Papers, Denver, 1, 578, 1973.
- Starrfield, S., J. W. Truran, W. M. Sparks, G. S. Kutter, "CNO Abundances and Hydrodynamic Models of the Nova Outburst", Astrophys. J., 176, 169, 1972.
- Vidor, S. B., "Observations of Nitrogen and Oxygen Isotopes in the Low Energy Cosmic Rays", Ph.D. Thesis, Calif. Inst. of Tech., 1975.
- Webber, W. R., J. A. Lezniak, J. Kish, S. V. Damle, "The Relative Abundance of the Isotopes of Li, Be, and B and the Age of Cosmic Rays", Astrophys. and Space Sci., 24, 17, 1973.